

A comparison of the globular cluster luminosity functions of the inner and outer halo of the Milky Way and M31.

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ABSTRACT

We show that the globular cluster luminosity function (GCLF) of the inner halo of the Milky Way is statistically different from the GCLF of the outer halo. We also find a similar difference between the inner and outer halo population of M31. We assert that this difference is evidence for some form of dynamical evolution of the cluster population and/or a dependence of GCLF shape on the environment in which the cluster population formed. We also find that the turnover luminosity of the GCLF is unaffected by these differences and further assert that this stability of the turnover luminosity affirms its usefulness as an indicator of cosmic distance.

Key words: globular cluster:general – galaxies:M31 – Galaxy:halo

1 INTRODUCTION

The globular cluster system of the Milky Way has long been known to be a multiple component system that can be divided into disk and halo subsystems; in addition, the halo subsystem can be further divided into an inner and outer halo (Searle and Zinn 1978). This division of the halo into inner and outer components has allowed the discrimination of the clusters along age boundaries on the basis of horizontal branch type (Lee *et. al* 1994), and the picture of inside-out galaxy formation now seems secure. For an excellent review of these issues see Zinn (1996) and other works in the same volume.

Consistent with the emerging acceptance of an inside-out picture of galaxy formation has come the view that the current population of globulars is not the primordial distribution but rather the surviving component of a once grander population (Fall and Rees 1977; Murali and Weinberg 1996). Most recently, a very appealing picture has been presented in which outer halo clusters do not suffer significant disruption while those which are interior to $R_{GC} \sim 8kpc$ do. (Murali and Weinberg 1996).

Given both that the outer halo clusters are younger and that their orbits make them less likely to have undergone externally imposed dynamical evolution, the outer halo cluster population should be most like that of a primordial system while that of the inner halo should be evolved. This reasonable view can be tested by a comparison of the globular cluster systems (hereafter GCSs) of the inner and outer halo. To

allow an extension of this comparison to external galaxies, the comparison should be between observables which can be studied in remote systems. The globular cluster luminosity function (GCLF) is the obvious choice.

2 THE MILKY WAY GCLF, INSIDE AND OUT

Figure 1 shows (a) the GCLF for all of the halo clusters of the Milky Way, and the GCLFs for the inner (b) and outer (c) halo subsystems. (These data were taken from the McMaster University globular cluster database maintained by W.E. Harris[†]). There are approximately 50 clusters in each of the subdivisions and so the differences between these two distributions are decidedly real. A Kolmogorov-Smirnov comparison of the two populations gives a probability of less than 5% that the two distributions come from the same parent population. This evidence strongly suggests that the inner and outer halo populations have different formation histories and/or different evolutionary histories.

Fits of the function

$$A \exp(-(m - M_{TO})^2 / (2\sigma^2)) \quad (1)$$

to the three distributions are overlaid on the histograms in Figure 1, with the numerical results shown in Table 1. These fits were performed using the NGAUSSFIT routine in STSDAS under the assumption of Poisson sampling errors. It is of interest to note that although the inner and outer halo

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Table 1. Fits to the GCLFs for various components of the Milky Way GCS. These fits were performed using the NGAUSS-FIT package in STSDAS. The data are from the McMaster catalogue. Note that the peak or turnover magnitude remains constant (within uncertainties) for all components in the Galaxy but the outer halo population is significantly broader.

MW-GCS	M_{TO}	σ_{GCLF}	N
all clusters	-7.44 ± 0.15	1.08 ± 0.1	132
all halo clusters	-7.48 ± 0.15	0.90 ± 0.1	93
inner halo clusters	-7.47 ± 0.13	0.66 ± 0.1	49
outer halo clusters	-7.41 ± 0.4	$1.76 \pm .3$	44

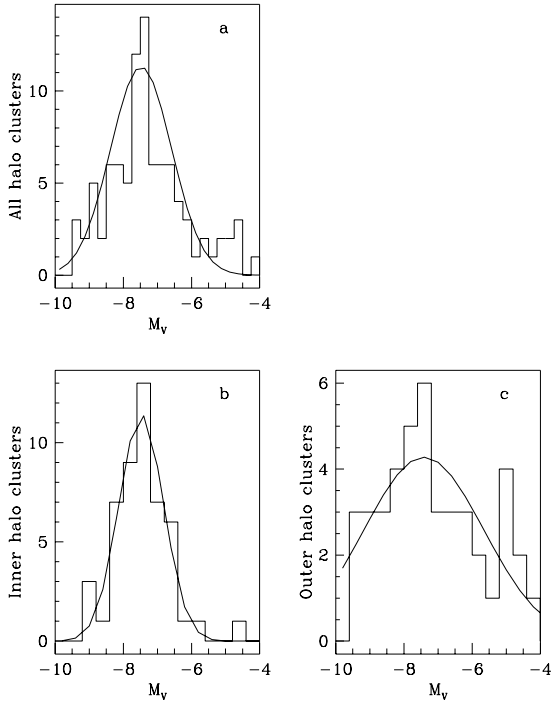


Figure 1. (a) The luminosity function for the halo globular clusters of the Galaxy. (b) The luminosity function for the inner halo clusters. (c) The luminosity function for the outer halo clusters. A Kolmogorov-Smirnov test shows that there is a 3.7% probability that the two distributions are drawn from the same parent population (ie. the hypothesis that these two distributions are from the same parent population is rejected).

GCLFs have markedly different distributions, they have the same peak luminosity. This result appears to be in conflict with recent dynamical models (Murali and Weinberg 1996) which suggest that the peak value of the GCLF will become significantly fainter as the cluster population evolves, and that such evolution should be strongest for the inner halo population.

3 THE GCS OF M31

The recognition of the two-component nature of the Milky Way halo cluster luminosity function immediately suggests an examination of the M31 GCLF under the same conditions. To allow such a comparison it is necessary to divide

the M31 cluster population into disk and halo subsystems. The question of which M31 clusters are halo members and which are disk members is confused by the lack of spectroscopic metallicities for a vast number of cluster candidates. Ideally a cut of metallicity similar to that used for the Milky Way would isolate the disk and halo subsystems, but in practice such a straightforward approach is not possible.

Previous authors have selected clusters as halo members based on their position on the sky (Reed *et al.* 1994). This selection criterion has the disadvantage of preferentially excluding many inner halo clusters. To avoid excluding objects on the basis of position we select as our “halo sample” all clusters for which $(B-V) < 0.8$ in the Battistini *et al.* (1987) survey. This selection seems justified in that for the Galaxy there are no disk clusters bluer than $(B-V) = 0.8$ and so this cut should eliminate the majority of disk clusters from the M31 sample. Unfortunately this selection criterion also removes many true halo members from the sample; however, we find that there is no significant difference in parameters between a Milky Way halo sample selected as $[\text{Fe}/\text{H}] < -0.8$ and one selected using $(B-V) < 0.8$. This culling also has the advantage of excluding background galaxies from the Battistini *et al.* (1987) A,B sample (see (Reed *et al.* 1992) Figure 8).

In panel (a) of Figure 2 we present the LF for all the globular cluster candidates which have $(B-V) < 0.8$ (from Battistini (1987)). In panel (b), we present the luminosity function for the subset of objects which lie within a projected radius of 10kpc (140 arcmin for a true distance modulus of 24.45 (Jacoby *et al.* 1992)) of the center of M31; in panel (c) we show the luminosity function for the objects beyond 10kpc. This figure qualitatively reveals the same separation of the GCLF into peaked and flat components, when selected on the basis of radius, as was seen for the Galaxy. We do not, however, consider this as strong a test as that afforded by the MW sample because of the uncertain extent to which incompleteness affects the luminosity functions in the subsamples at the faint end. In addition, of course, there will be some contamination of the “inner halo” subsample by outer halo clusters projected into the 10 kpc circle. Also, the determination of halo/disk membership for individual clusters is uncertain and it is probable that there is contamination of the inner halo sample by disk clusters.

Table 2 presents the results of fits of equation 1 to the various cluster populations in M31. As was found for the Milky Way GCS the outer halo clusters of M31 have a broader luminosity function, and once again there is no evidence for difference between the turnover luminosity of the inner and outer halo. A K-S comparison of the data sets gives a probability of 18% that the two samples are drawn from the same parent population. This provides marginal evidence for a multiple component halo and is consistent with previous work (Ashman and Bird 1993; Huchra *et al.* 1991) which has shown that the distribution of halo clusters in M31 contains substructure.

As for the Milky Way, the observed difference between the two M31 halo populations cannot be the result of dynamical evolution of the type predicted by Murali and Weinberg (1996) since their model implies that the inner population should appear fainter than that of the outer. There is no evidence for such a shift in turnover values.

Table 2. Fits to the GCLFs for various components of the Andromeda galaxy (M31). These fits were performed using the NGAUSSFIT package in STSDAS. The data are from Battistini *et. al* (1987). Once again, the outer halo population is somewhat broader than that of the inner halo sub-system.

M31-GCS	M_{TO}	σ_{GCLF}	N
all halo clusters	17.45 ± 0.08	0.76 ± 0.05	161
inner halo clusters	17.30 ± 0.10	0.57 ± 0.10	64
outer halo clusters	17.29 ± 0.17	0.94 ± 0.13	97

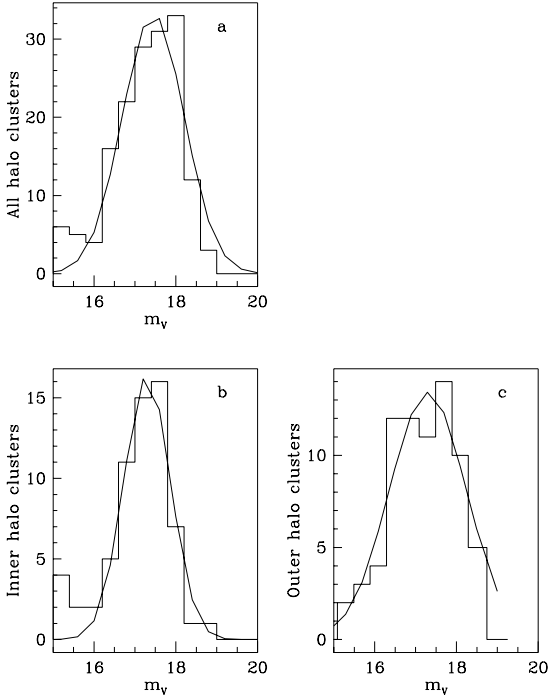


Figure 2. (a) The luminosity function for the halo globular clusters of the M31. (b) The GCLF for the inner halo clusters. (c) The GCLF for the outer halo clusters. A Kolmogorov-Smirnov test shows that there is a 18% probability that the two distributions are drawn from the same parent population (ie. the hypothesis that these two distributions are from the same parent population is not supported).

4 CONCLUSIONS

Both within the Milky Way and, to a lesser extent, M31 the outer halo clusters are clearly more indicative of a broad luminosity function. This population may be, then, indicative of an initial broad mass function for globular clusters.

The inner halo clusters demonstrate a remarkably peaked distribution. The difference between the inner and outer luminosity functions may indicate the fate that dynamical evolution has in store for clusters formed near the centers of galaxies.

The turnover luminosities of the inner and the outer cluster populations appear to be consistent. If this is the case, then dynamical models of cluster evolution will need to account for the preferential stripping away of clusters fainter and brighter than the turnover luminosity. This decoupling of mean luminosity from position in the galaxies gives fur-

ther assurance that GCLFs can be used as standard candles in cosmic distance determinations. The dependence of the shape of the GCLF on galactocentric radius suggests that future comparisons should be made between cluster populations that only include clusters of comparable radii from their host galaxy centers.

If dynamical effects are not found to be responsible for the dependence of GCLF shape on radius, then the environment in which clusters form is likely to be the deciding factor.

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